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Relation between Kink Effect and Impact Ionization Effect in SOI MOSFETs with Body Terminal

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The drain conductance method is very useful to evaluate the kink effect in SOI MOSFETs. The kink current extracted based on the drain conductance method has excellent correlation with body terminal current and the emitted photon number in SOI MOSFETs when zero or negative bias voltage is applied to the silicon substrate. The kink effect caused by the impact ionization at the back channel was observed when a positive voltage is applied to the substrate.

Introduction

SOI MOSFETs have been attracting much attention as potential candidate for high-performance deep-submicron or further scaled-down devices due to increased current drivability, reduced short channel effect, steep subthreshold slope and smaller parasitic capacitance. However, SOI MOSFETs have the disadvantage that I_D-V_D characteristics are seriously degraded by the harmful kink effect. Then, the kink effect in SOI MOSFETs is investigated in detail by measuring the kink current together with the body terminal current and the hot carrier photon emission changing a temperature and a substrate bias voltage applied to the bottom silicon substrate.

Experimental

SOI MOSFETs with the body terminal as shown in Fig.1 were fabricated on SIMOX wafer according to the conventional CMOS process. The SOI film thickness is 100nm and the buried oxide thickness is 400nm. The gate oxide thickness is 15nm. The kink current was extracted from I_D-V_D characteristics based on the drain conductance method as described in Fig.2 [1][2]. The photon emission characteristics were measured by Hamamatsu hot-electron analyzer.

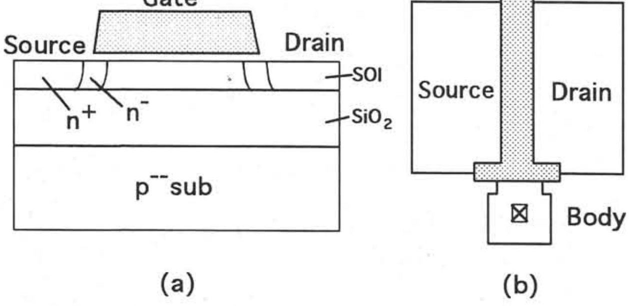

Fig.1 Cross-sectional and plane view of SOI MOSFET with body terminal.

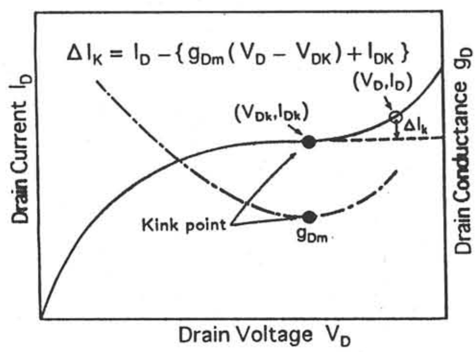

Fig.2 Drain conductance method.

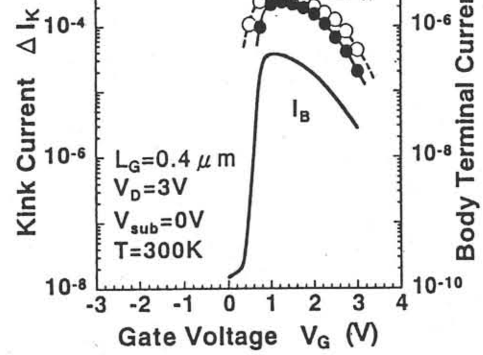

Fig.3 Gate voltage dependences of kink current and body terminal current.

Results and Discussion

The gate voltage dependence of the kink current ΔI_K is plotted in Fig.3 for two cases where the body terminal is floated and fixed at 0V. In the figure, the body terminal current I_B is also plotted. As is obvious in the figure, the characteristics show a typical bell-type shape similar to that of substrate current in the bulk MOSFET. The kink current ΔI_K for the case of the float-

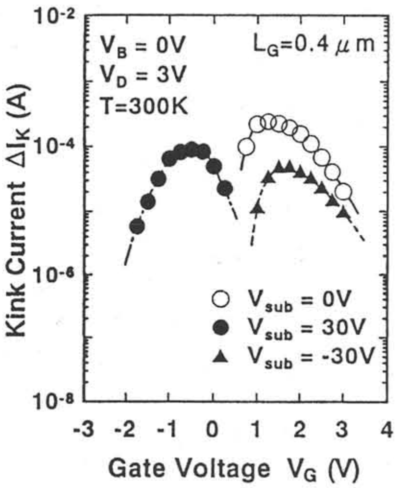

Fig.4 Gate voltage dependence of kink current.

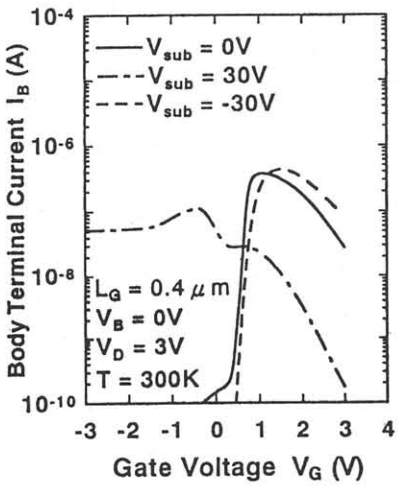

Fig.5 Gate voltage dependence of body terminal current.

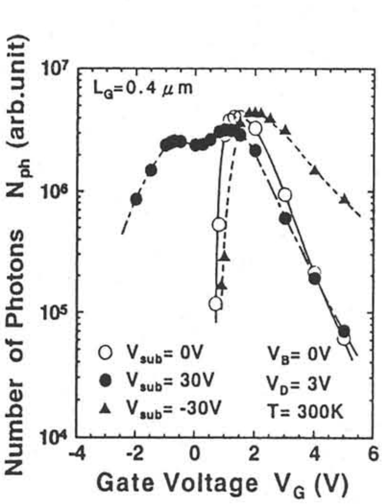

Fig.6 Gate voltage dependence of emitted photon number.

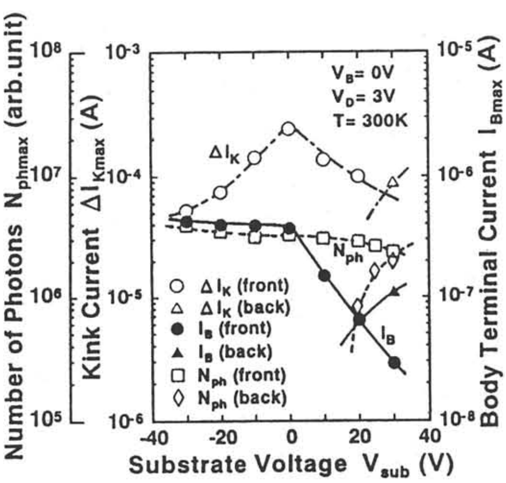

Fig.7 Substrate voltage dependence of maximum body terminal current, kink current and photon number.

ing body terminal is slightly larger than that of the fixed body terminal because the parasitic bipolar action is more pronounced in the case of the floating body terminal. It is also obvious in the figure that a very clear correlation between ΔI_K and I_B is obtained in the case of the substrate bias voltage V_{sub}=0V. However, I_B is around three orders of magnitude smaller than ΔI_K. ΔI_K and I_B are plotted again as a function of gate voltage changing the substrate voltage as a parameter in Figs. 4 and 5. The shape of both characteristics is similar each other for V_{sub}=0V and $V_{sub}=-30$V. The maximum body terminal current slightly increases when the substrate voltage is changed from 0V to -30V. On the contrary, the kink current significantly decreases because the back surface of SOI film is accumulated more and consequently holes generated by the impact ionization can be more easily swept out from the body terminal when high negative voltage is applied to the silicon substrate. When high positive voltage is applied to the substrate, the shape of the characteristics significantly changes. Two peaks are observed in I_B-V_G characteristics. The first peak in the lower gate voltage region is due to the impact ionization at the back channel while the second peak in the higher gate voltage region due to the impact ionization at the front channel. The first peak is larger than the second peak. A relatively large kink current due to the impact ionization at the back channel is observed in the lower gate voltage region. The photon emission characteristics in SOI MOSFET with body terminal are shown in Fig.6. Typical bell-type shape similar to ΔI_K-V_G and I_B-V_G characteristics is obtained for V_{sub}=0V and $V_{sub}=-30$V. The peak value increases as V_{sub} is changed from 0V to -30V because the channel electric field increases. Two peaks are observed also in N_{ph}-V_G characteristics for V_{sub}=+30V. However, the second peak is larger than the first peak in contrast to I_B-V_G and ΔI_K-V_G characteristics. This means that although the impact ionization still significantly occurs even in the gate voltage region for the second peak, only a part of generated holes flow into the body terminal because the SOI film body is inverted at the front surface and is depleted inside and at the back surface. The maximum kink

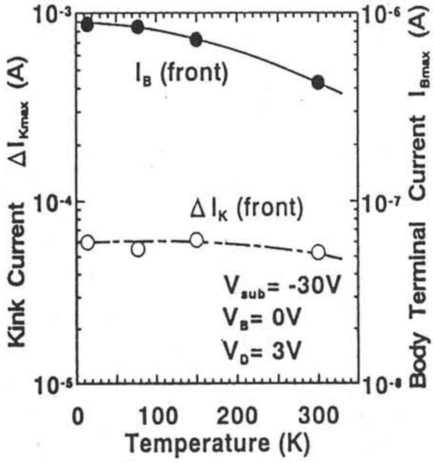

Fig.8 Temperature dependence of body terminal current and kink current at V_{sub}=-30V.

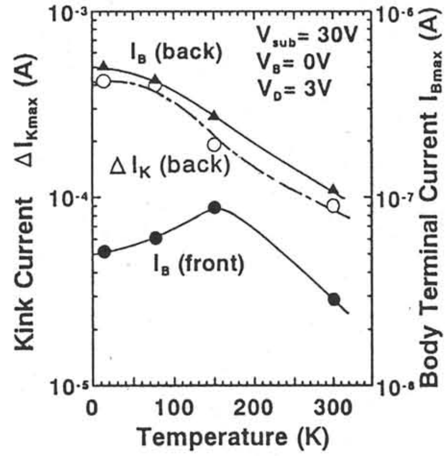

Fig.10 Temperature dependence of body terminal current and kink current at V_{sub}=+30V.

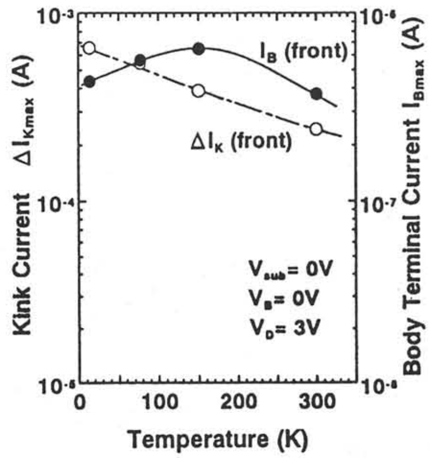

Fig.9 Temperature dependence of body terminal current and kink current at V_{sub}=0V.

current ΔI_{Kmax}, body terminal current I_{Bmax} and emitted photon number N_{phmax} are plotted as a function of substrate voltage in Fig.7. As is clear in the figure, both I_{Bmax} and N_{phmax} slightly increase as the substrate voltage is increased to a negative direction because the channel electric field increases. On the other hand, ΔI_{Kmax} decreases because the back surface of SOI film body is accumulated and generated holes are easily swept out from the body terminal. When a positive high voltage is applied to the substrate, I_{Bmax} due to the impact ionization at the front channel significantly decreases because it becomes difficult for holes to flow into the body terminal. I_{Bmax} due to the impact ionization at the back channel is observed in a higher substrate voltage region. N_{phmax} only slightly decreases even if a positive high voltage is applied to the substrate because the impact ionization still significantly occurs [3]. Meanwhile, the kink current decreases as the substrate voltage is increased to the positive direction because the barrier height in the source junction at the back surface is reduced and generated holes more easily flow into the source without hole accumulation in the SOI film near the source. Thus, ΔI_{Kmax} represents the peak around V_{sub}=0V.

Temperature dependences of I_{Bmax} and ΔI_{Kmax} for $V_{sub}=-30$V, 0V and +30V are shown in Figs.8 to 10, respectively. In the case of $V_{sub}=-30$V, I_{Bmax} increases while ΔI_{Kmax} only slightly increases as a temperature is reduced because the kink current is effectively suppressed by the body terminal. On the other hand, in the case of V_{sub}=+30V, I_{Bmax} due to the impact ionization at the front channel initially increases and then decreases because the body terminal resistance increases and only smaller amount of holes flow into the body terminal in the lower temperature. ΔI_{Kmax} monotonously increases as a temperature is lowered because the impact ionization becomes more significant and the barrier height at the source junction increases.

Conclusion

It has been shown that the drain conductance method is very useful to evaluate the kink effect in SOI MOSFETs. The kink current extracted based on the drain conductance method has excellent correlation with body terminal current and the emitted photon number in SOI MOSFETs when zero or negative bias voltage is applied to the silicon substrate. The kink effect caused by the impact ionization at the back channel was observed when a positive voltage is applied to the substrate. Both kink currents observed at the front channel and the back channel increased as the temperature was reduced.

Acknowledgment

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References

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